Biotechnology

Nanotechnology

Nanotechnology Capability Roadmap

Public Meeting

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Information Technology

Roadmap Co-Chairs:

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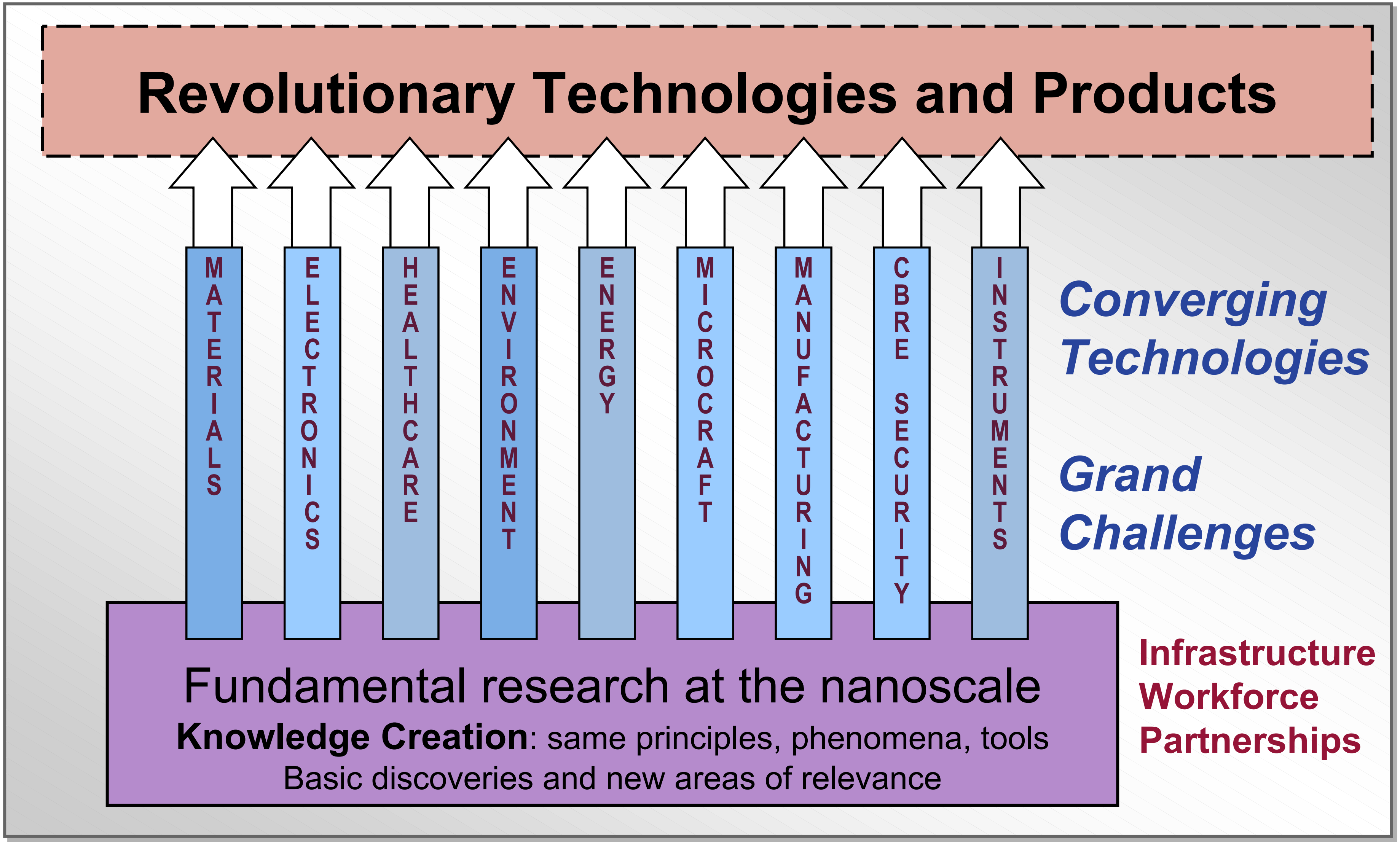
Capability Roadmap: Nanotechnology

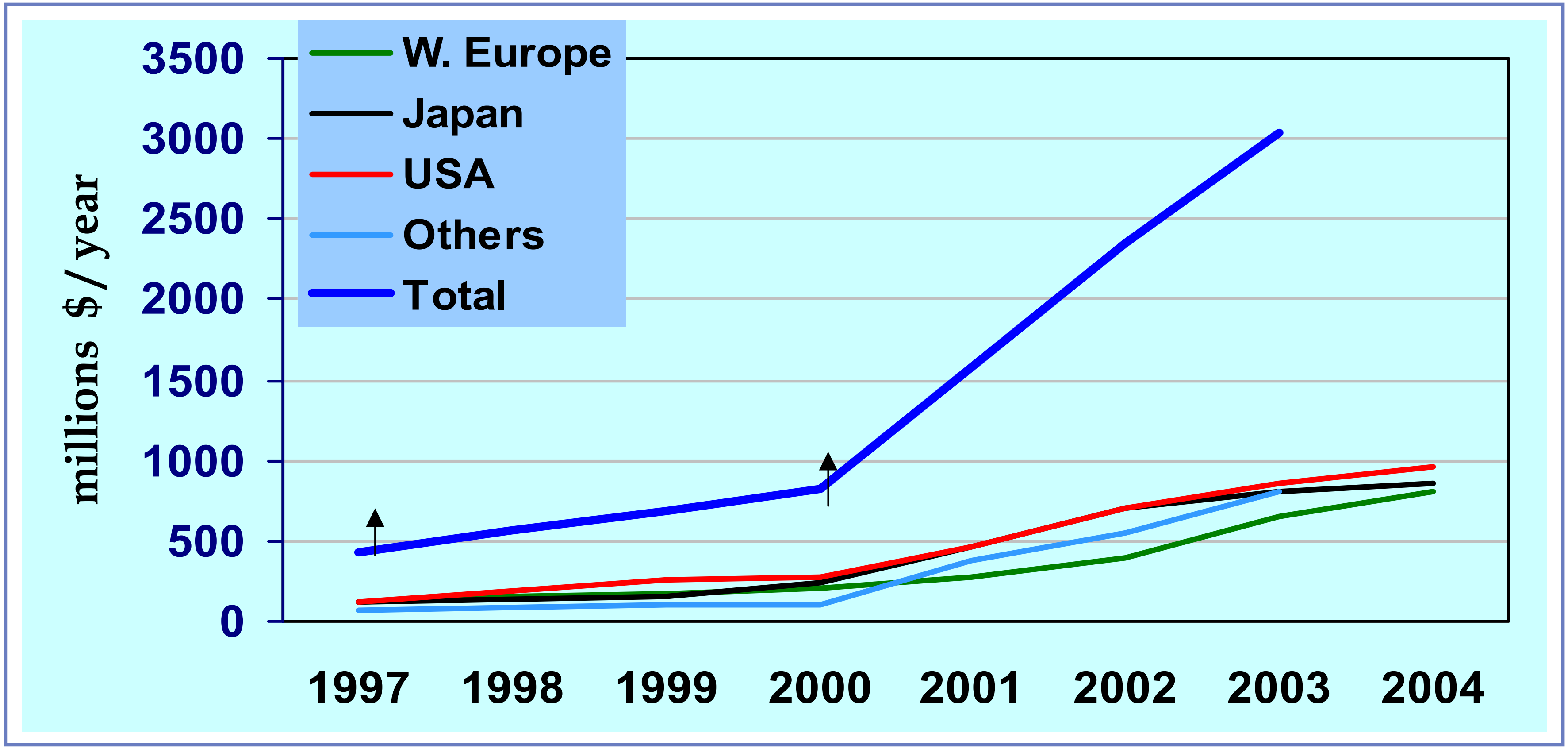
National Nanotechnology Initiative



Capability Roadmap: Nanotechnology

Government investments 1977-2004

(estimation NSF)



- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)
- "Others" includes Australia, Canada, China, E. Europe, FSU, Israel, Korea, Singapore, Taiwan

Overarching Challenges

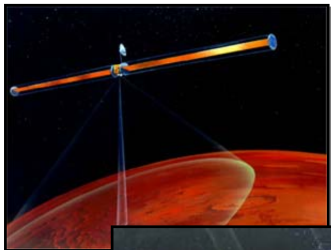
- Performance in Extreme Environments (Radiation, Temperature, Zero Gravity, Vacuum)
- Frugal Power Availability
- High Degree of Autonomy and Reliability
- Human “Agents” and “Amplifiers”

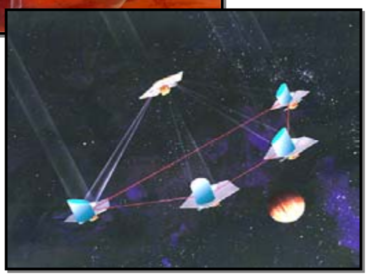
Capability Roadmap: Nanotechnology

Future Challenges: Space Systems

Many of NASA's challenges are not achievable by extensions of current technology

Size per Mass

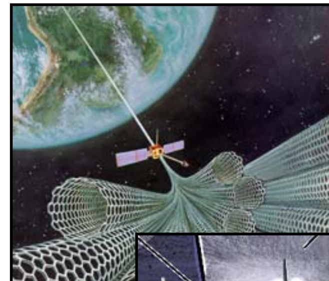


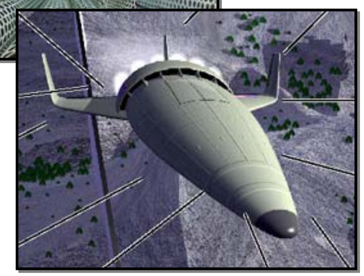


- **Ultra-large apertures**
- **Solar sails**
- **Gossamer spacecraft**

Diameters > 25-50 m are not achievable by extension of current materials technologies

Strength per Mass

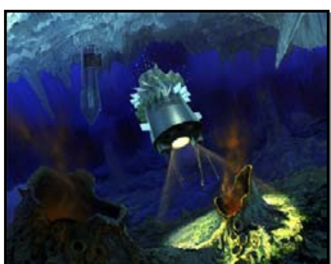


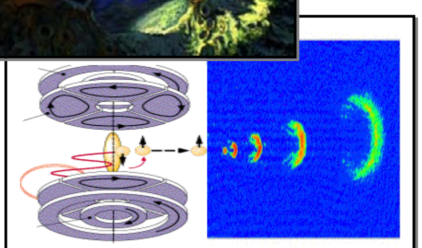


- **Air/launch/space vehicles**
- **Human habitats in space**
- **Self-sensing systems**

Factors of 10 - 100 are not achievable by current materials options

Capability per Mass & Power

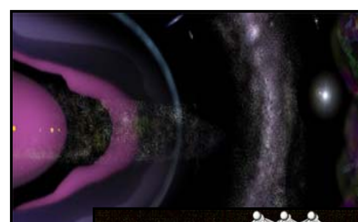


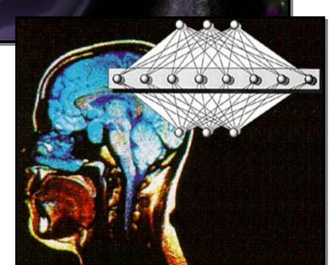


- **Microspacecraft**
- **Quantum-limited sensors**
- **Biochem lab-on-a-chip**

Conventional device technologies cannot be pushed much farther

Intelligence per Mass & Power





- **Medical autonomy**
- **AI partners in space**
- **Evolvable space systems**

Current information processing technologies are approaching their limit, and cannot support truly autonomous space systems

Capability Roadmap: Nanotechnology

Future Challenges: Exploration Systems

US Strategic Vision

Productivity

- Human-Machine Symbiosis
- Sensors/Nano-electronics/ Computing
- Data Mining
- Full Cells/Energy Storage

Safety

- Radiation
- Life Support
- Counter Measures
- Vehicle Health Mgmt.

Cost

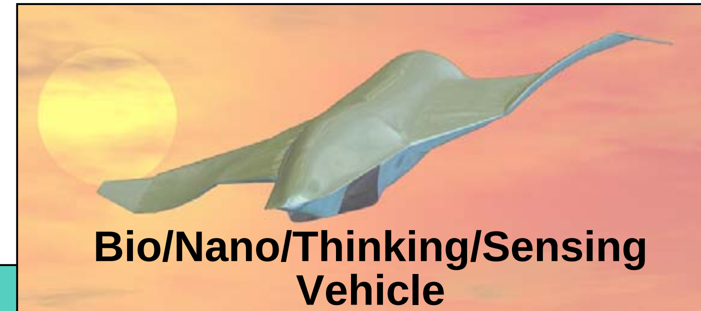
- High Strength/Light Weight
- Multifunctionality
- Thermal Management

Capability Roadmap: Nanotechnology

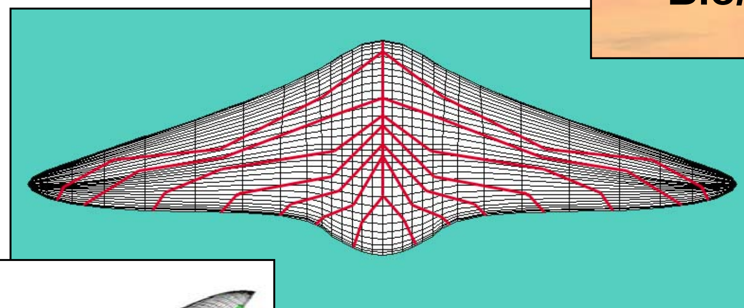
Future Challenges : Aeronautics

Advanced Technology Development

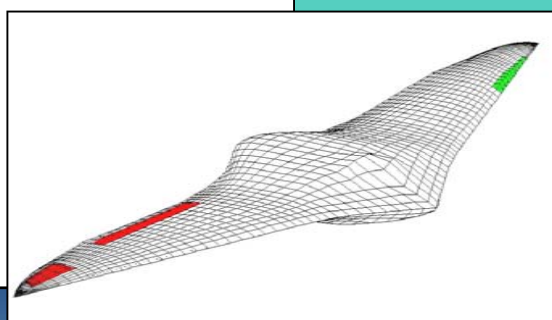
- Distributed self-assessment and repair
- Adaptive shape control
- Highly efficient propulsion
- Exploits Bio-Nano-Info technology revolution



Bio/Nano/Thinking/Sensing Vehicle



Self-Healing Structure with "Central Nervous System"



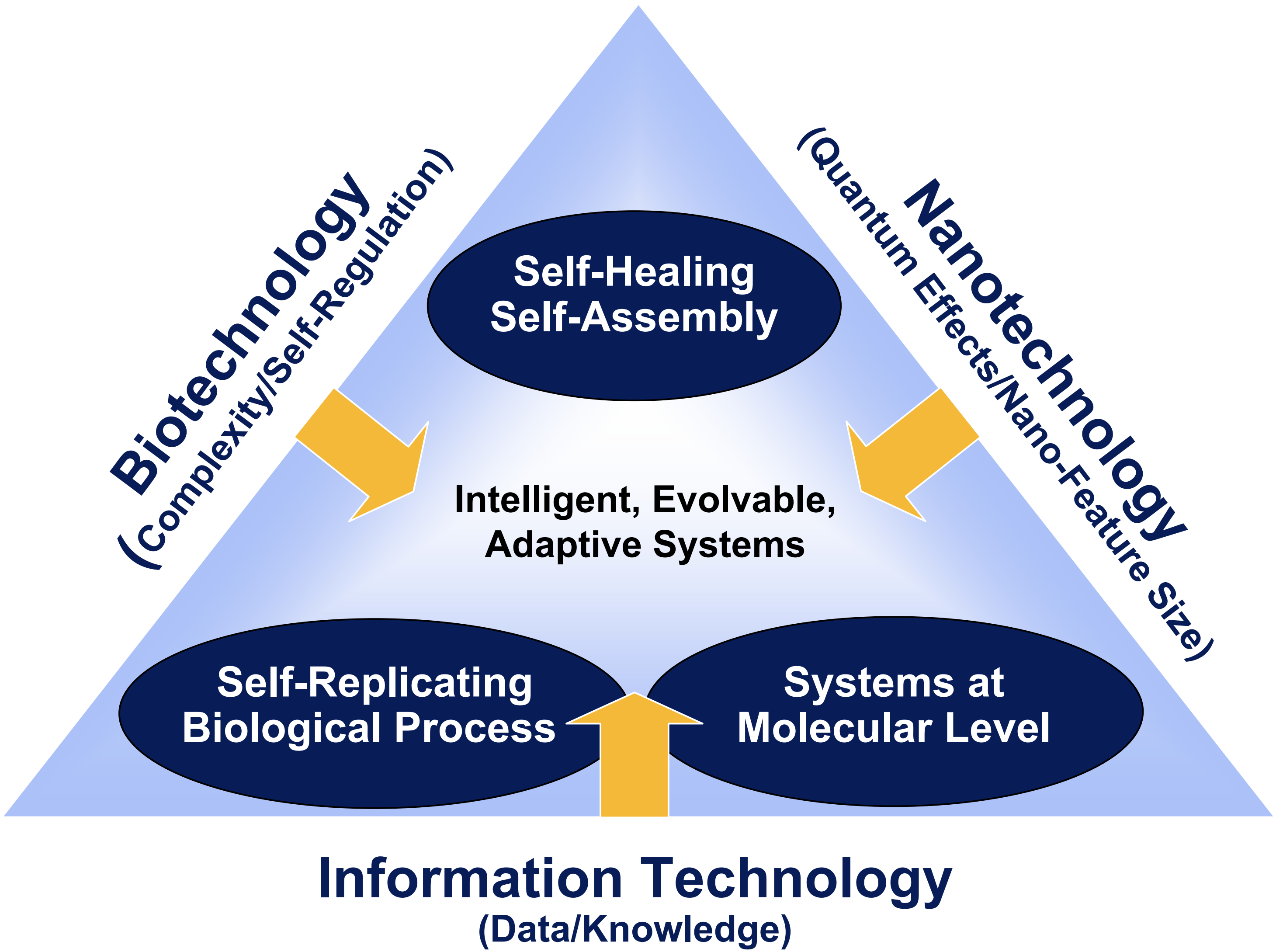
Smart Structure with Active Flow Control

Modern Advanced Metal Aircraft

- Ultra Safe
- Whisper Quiet
- "Zero" Emissions
- Extreme Maneuverability
- High Survivability
- Ultra Low Fuel Burn

Time

Capability Roadmap: Nanotechnology
Revolutionary Technology Vision: The "Zone of Convergence"



Current Nanotechnology Investment Areas

- **Nanostructured Materials**
  - High strength/mass, smart materials for aerospace vehicles and large space structures
  - Materials with programmable optical/thermal/mechanical/other properties
  - Materials for high-efficiency energy conversion and for low temperature coolers
  - Materials with embedded sensing/compensating systems for reliability and safety
- **Nano Electronics and Computing**
  - Devices for ultra high-capability, low-power computing & communication systems
  - Space qualified data storage
  - Novel IT architecture for fault and radiation tolerance
  - Bio-inspired adaptable, self-healing systems for extended missions
- **Sensors and Microspacecraft Components**
  - Low-power, integrable nano devices for miniature space systems
  - Quantum devices and systems for ultrasensitive detection, analysis and communication
  - NEMS flight system @ $1 \mu W$
  - Bio-geo-chem lab-on-a-chip for in situ science and life detection
- **University Research Engineering and Technology Institutes**
  - Bio-nano-information technology fusion (UCLA)
  - Bio-nanotechnology materials and structures (Princeton)
  - Bio-nanotechnology materials and structures (Texas A&M)
  - Nanoelectronics computing (Purdue)

Context

- "Nanotechnology" is broad term encompassing the manipulation and control of matter on the scale of 1 nm to 100 nm to achieve desired properties and behavior

- The significance of nano-scale technology is in the unique and exceptional properties that are present at that scale

- Nano-scale technology is pervasive and affects essentially all areas of technology important to NASA

- New skills, talents, and research and development methodology are required to fully benefit from the capabilities arising from technology at the nano-scale

- It is strategically important for NASA to exploit and benefit from rapidly emerging discoveries at the nano-scale

Capability Roadmap: Nanotechnology

Plan / Approach

- **Build on 5+ years of similar activity including prior roadmaps and involvement in the National Nanotechnology Initiative (NNI)**
  - Recent planning for the second 5 years of NNI
  - NASA NNI workshop Microcraft and Robotics
  - Recent workshop among the four NASA University, Research, Engineering and Technology Institutes in nanotechnology (URETI)
  - Utilize existing informal NASA team, including URETIs, that has evolved over the past several years
- **The scope will include both aeronautics and space**
  - Both near and mid-term opportunities and long-term vision
  - Tie development of capability to enabling higher level applications
  - Key demonstrations and quantifiable milestones to gage progress
- **Focus on fundamental underlying technological capability, such as**
  - Theory and analysis from the nano-scale to the macro-scale to predict properties and behavior
  - Materials processing for desired properties and behavior
  - Design and development of devices and systems based on nano-scale technology
  - Integration of nano-scale devices and systems into micro- to macro- systems
  - Training and Education

Scope of Roadmap Content

- Methodology for Multi-scale Analysis and Modeling from the Nano-scale to the Meso-scale
- Advanced Nano-Scale Materials
- Concepts for Nano-Scale Devices
- Nano-to-Micro Systems Integration

Multi-scale Analysis and Modeling

- Quantum mechanics
- Molecular Dynamics
- Nano-to-Micro Modeling
- Integrated Nano-Micro System Modeling
- Nanoscale Design and Reliability
- Biomimetic Modeling

Advanced Nano-Scale Materials

- Vehicle Structural Materials (e.g. carbon nanotube based composites)
- Damage Tolerant Self-Healing Materials
- High Temperature Structural Materials (e.g. silicon-carbide or boron nitride nanotube based composites)
- Nano-crystalline Materials (e.g. nanoscale powder metallurgy)
- Space Durable Materials for Nano-scale Electronics and Sensors
- Advanced Power and Propulsion Materials (e.g. carbon nanotube electrodes for batteries, quantum dots for PV cells)
- Tribology (e.g. lubrication)
- Biomimetic Materials
- Multi-functional Materials (e.g. deformable materials within imbedded energy generation, storage, actuation and health monitoring

Capability Roadmap: Nanotechnology

Nanoscale Devices

- Transistors/Logic Gate
- Memory Cell
- Quantum Wells and Quantum Dots
  (e.g. lasers, energy conversion)
- Chemical Detection (e.g. DNA-based detector)
- Photon/electron Detection
- Mechanisms
  (e.g. actuators, accelerometers, gyro, etc)

Nano-to-Micro Systems Integration

- NEMS (nano-electro-mechanical systems)
- Sensor and Detector Concepts
- 3-D Computing Architectures
- Large Arrays

Capability Roadmap: Nanotechnology

Summary

NOVEL PHENOMENA

Present Phase

- Production of Nanomaterials
- Characterization at Atomic/Bulk Scale
- Nanoscale Modeling and Simulation

Next Phase

- Integration of “Nanoworld” with the “ Macroworld”
- Integration of Wet World with Dry World
- Emergence of Intelligence from Complexity
- Multi-scale Modeling and Simulation Hierarchy

NOVEL PHYSICS (NANOSCALE)

Capability Roadmap: Nanotechnology

Team

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